Probe Initial Parton Density and Formation Time via Jet Quenching *

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In high-energy heavy-ion collisions, one of the pressing issues is the direct determination of the initial parton density of the dense medium and its formation time. Jet quenching or attenuation of leading particles from jet fragmentation can provide an effective tool to measure directly the parton density of the medium with which the jet interacts strongly during its propagation. Recent theoretical studies have shown that parton energy loss via induced radiation is directly related to the gluon density of the medium. The attenuation will suppress the final leading hadron distribution giving rise to modified parton fragmentation functions. By measuring the medium modification of the fragmentation function one can thus extract the effective parton energy loss. Most importantly, one can compare the effective parton energy loss extracted from heavy-ion collisions to that of cold nuclei and extract the initial parton density of the hot dense medium relative to a cold nucleus.

The predicted shape of the z- and and energy dependence of modified fragmentation function in DIS agrees well with the experimental data. A remarkable feature of the prediction is the quadratic $A^{2/3}$ nuclear size dependence, which is verified for the first time by an experiment. The only parameter in our calculation is found to be $\widetilde{C}(Q^2) = 0.0060$ GeV^2 with $\alpha_s(Q^2) = 0.33$ at $Q^2 \approx 3$ GeV^2. If one defines theoretically the quark energy loss as that carried by the radiated gluons, then the averaged total energy loss is,

$$\Delta E = \nu\langle\Delta z_g\rangle \approx \widetilde{C}\alpha_s^2(Q^2) m_N R_A^2 (C_A/N_c) 3\ln(1/2x_B). \quad (1)$$

With the determined value of $\widetilde{C}$, $\langle x_B\rangle \approx 0.124$ in the HERMES experiment and the average distance $\langle L_A\rangle = R_A\sqrt{2/\pi}$ for the assumed Gaussian nuclear distribution,one gets the quark energy loss $dE/dL \approx$ 0.5 GeV/fm inside a Au nucleus.

One can also calculate the transverse momentum broadening of the quark jet which is also related to a similar twist-four parton matrix elements.

$$\langle \Delta q_\perp^2\rangle = \frac{2\pi\alpha_s}{N_c}\frac{\widetilde{T}^A_{qg}(x_B)}{q_A(x_B)} \approx \widetilde{C}\frac{\pi\alpha_s}{N_c} m_N R_A \approx 0.011 A^{1/3}\mathrm{GeV}^2 \quad (2)$$

Fitting the PHENIX data on suppression of large p_T π_0 spectra yields $\langle dE/dL\rangle_{1d} \approx 0.34\ln E/\ln 5$ GeV/fm. Taking into account the expansion, this would be equivalent to $(dE/dL)_0 = 0.34(R_A/2\tau_0)\ln E/\ln 5$ in a static system with the same gluon density as the initial value of the expanding system at τ_0. With $R_A \sim 6$ fm and assuming $\tau_0 \sim 0.2$ fm, this would give $(dE/dL)_0 \approx 7.3$ GeV/fm for a 10-GeV parton, Since the parton energy loss is directly proportional to gluon density of the medium, this implies that the gluon density in the initial stage of $Au+Au$ collisions at $\tau_0 = 0.2$ fm/c is about 15 times higher than that inside a cold nucleus. To extract the parton density and the initial formation time, one has to measure the energy loss and q_T broadening simultaneously.

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